Human Health & Performance Aspects of a Mars Mission

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MARS

Workshop Focus: Understand the ways humans and machines can synergistically be combined to enhance or accelerate the science return

1. identification of advanced, revolutionary systems concepts,
2. identification of required technologies to enable these capabilities,
3. an evaluation of the evolution of the relative roles of humans and machines to implement these concepts
4. an identification of the science that would be enabled by these capabilities.

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Reality

- Human beings won't evolve over the next 40 years enough to make our job easier.
- New technologies can make it easier to keep humans healthy during this time.
- Less time and mass spent on medical tasks will free up mass and crew time to 'do science.'
- Nearly all NASA research in BioAstronautics is focused through the ISS program.
- Other relevant research is being performed outside of NASA which can amplify human capabilities.

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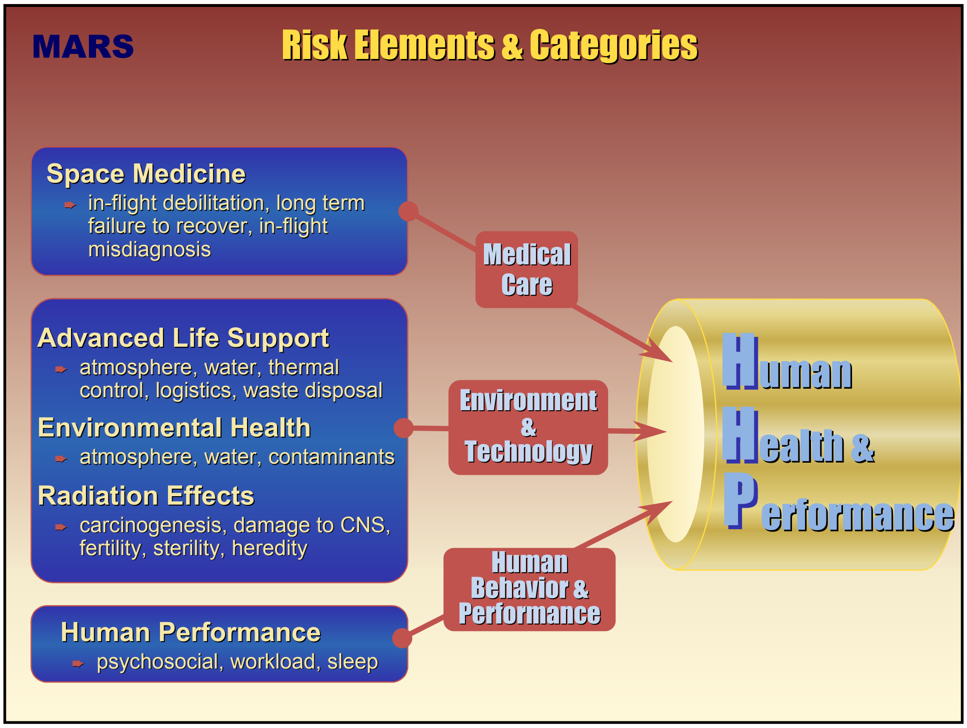
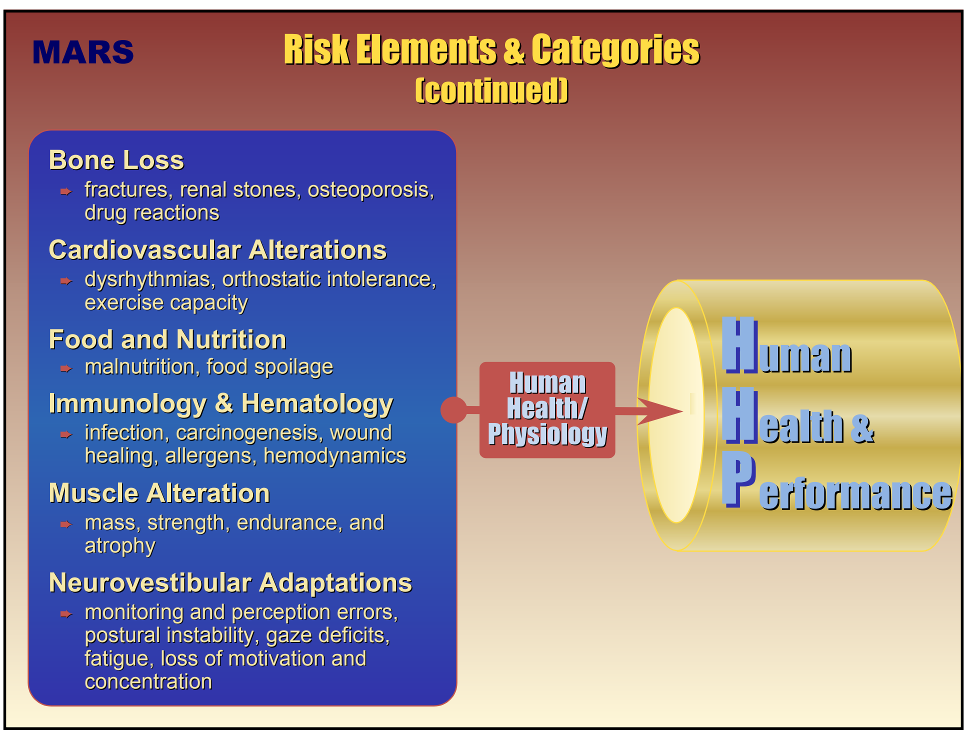
Requirements

Human Health & Performance during long-duration space flights

- **Basic Elements**
  - Nutrition (adequate, appropriate, appealing)
  - Rest (avoid chronic fatigue)
  - Exercise (fitness, recreation, motivation)
  - Human Performance (psychosocial, workload, & circadian factors)
- **Habitability** including advanced life support & environmental health
- **Countermeasures & preventive measures** for deleterious physiological effects
- **Diagnosis** of new or pre-existing conditions
- **Treatment** subsequent to diagnosis
- **Research** directed towards fulfilling all of the above


MARS
Risk Elements & Categories
Space Medicine
in-flight debilitation, long term failure to recover, in-flight misdiagnosis
Advanced Life Support
atmosphere, water, thermal control, logistics, waste disposal
Environmental Health
atmosphere, water, contaminants
Radiation Effects
carcinogenesis, damage to CNS, fertility, sterility, heredity
Human Performance
psychosocial, workload, sleep
Medical Care
Environment & Technology
Human Behavior & Performance
Human Health & Performance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Risk Elements & Categories (continued)
Bone Loss
fractures, renal stones, osteoporosis, drug reactions
Cardiovascular Alterations
dysrhythmias, orthostatic intolerance, exercise capacity
Food and Nutrition
malnutrition, food spoilage
Immunology & Hematology
infection, carcinogenesis, wound healing, allergens, hemodynamics
Muscle Alteration
mass, strength, endurance, and atrophy
Neurovestibular Adaptations
monitoring and perception errors, postural instability, gaze deficits, fatigue, loss of motivation and concentration
Human Health/ Physiology
Human Health & Performance

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Physical Challenges

Radiation

	Earth Launch	Transit	Mars Landing	Mars Surface	Mars Launch	Transit	Earth Return
Source	van Allen belts (trapped radiation)	GCR (quiet sun); SPE (active sun); nuclear power reactor		GCR (quiet sun); SPE (active sun); nuclear power reactor		GCR (quiet sun); SPE (active sun); nuclear power reactor	van Allen belts (trapped radiation)
Exposure		4-6 months		18 months; shielded by Mars' bulk & atmosphere		4-6 months	
Cumulative Exposure	hours-days		4-6 months		22-24 months		26-30 months

GCR: galactic cosmic radiation
SPE: solar particle events
SEP: solar electric propulsion

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Physical Challenges

Gravity .... Acceleration

	Earth Launch	Transit	Mars Landing	Mars Surface	Mars Launch	Transit	Earth Landing
G-Load	up to 3 g	0 g	3-5 g	0.38 g	TBD g	0 g	3-5 g
Notes	boost phase (8min); TMI (min)	4-6 months	aerobraking (min); parachute braking (30s); powered descent(30s)	18 months	boost phase (min); TEI (min)	4-6 months	aerobraking (min); parachute braking (min)
Cumulative hypo-g	0		4-6 months		22-24 months		26-30 months
G transition	1 g to 0 g		0 g to .38 g		.38 g to 0 g		0 g to 1g

TMI: trans-Mars injection
TEI: trans-Earth injection

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Impacts of Extended Weightlessness

Physical tolerance of stresses during aerobraking, landing, and launch phases, and strenuous surface activities

Bone loss
- no documented end-point or adapted state
- countermeasures in work on ground but not yet flight tested

Cardiovascular alterations
- pharmacological treatments for autonomic insufficiency

Muscle atrophy
- resistive exercise under evaluation

Neurovestibular adaptations
- vehicle modifications, including centrifuge
- may require auto-land capability

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Current Countermeasure Concepts

- bone
  - resistive exercise, bis-phosphonates, ..., artificial gravity
- muscle
  - resistive exercise, aerobic exercise, hormones, ..., artificial gravity
- cardiovascular
  - LBNP, aerobic exercise, ..., artificial gravity
- neurosensory
  - artificial gravity, ???

CM Concerns

- research/development/evaluation/validation
  - time, cost, flight resource requirements
- operational effectiveness
  - interactions, side effects, complexity, crew time, crew compliance

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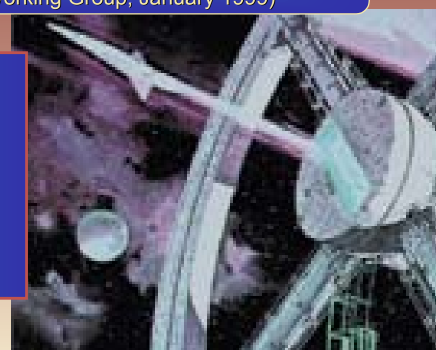
Artificial Gravity (AG)

What steps are required to certify AG as a valid countermeasure to extended weightlessness?
(per Artificial Gravity Working Group, January 1999)



- **Begin a comprehensive ground research program immediately**
- **Begin a parallel flight research program as soon as possible**
  - The ISS small-animal centrifuge will *not* be available before CY2004
  - A larger centrifuge is currently not planned at all!

- **Focus on the following research priorities**
  - Minimize physiological effects by developing optimal prescriptions for intermittent AG
  - Identify g threshold values needed to maintain HHP (including .38 g exposure for 18 months)
  - Determine optimal AG characteristics (e.g., radius and angular velocity)

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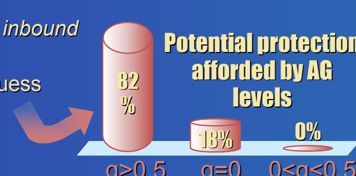
Artificial Gravity Considerations

Can artificial gravity preserve physiological function during long-duration missions?

Actions needed to accomplish Mars mission transit

- **Vigorously investigate** AG to reach a consensus about AG for Mars mission
- **Explore current approach**: AG may be used to pre-adapt crew to Mars gravity (outbound) and re-adapt to Earth gravity (inbound):
  - provides extended physiological protection from 1 g
  - eases transition throughout 3/8 g exposure
  - requires AG capability of 1 g outbound and *inbound*
- **Define parameters** for optimal g level
  - initiate benchmark studies based on best guess
  - evaluate protective effects (if any) of 3/8 g
  - continue studies on optimal angular rate:
    - few problems if $\omega < 1$ rpm
    - some problems if $1 > \omega > 6$ rpm
    - more problems if $6 > \omega > 10$ rpm
    - no data if $\omega > 10$ rpm



Note: no consensus currently exists on AG levels needed for exploration missions

MARS

LEO Artificial-G / Technology Demo Mission

Rationale: When people land on Mars, it should NOT be our first time for extended stays at 0.38 g

- Experience gained at 0.38 g will improve designs for biomedical equipment, habitats, etc., thus reducing risk and mass for items landed on Mars.
- Gaining biomedical experience at 0.38 g in LEO will remove any confounding influence of Mars dust, interplanetary levels of radiation, and transit time at 0-g.
- This could reduce the required equipment and crew time to and from Mars, and especially on the surface.
- More time and mass are thus available for science.

MARS

LEO Artificial-G / Technology Demo Mission

- Tests, demos, and research that can be considered in an Artificial-G facility in LEO include:
  - Bone density vs. time as a function of artificial gravity level.
  - Muscle strength vs. time as a function of artificial gravity level.
  - Cardiopulmonary function vs. time as a function of artificial-g level.
  - Neurological adaptation to a rotating environment at varying rates.
  - Behavior in a rotating, confined environment
  - Any countermeasure effectiveness still required at 0.38 g.
  - Gravitational ecology (microbiology) at hypogravity.
  - Medical support and emergency care procedures at 0.38 g
  - Habitability / stowage designs, issues, & opportunities at 0.38 g.
  - Testing and demo of Advanced Life Support Systems in a rotating environment at 1 and 0.38 g
  - EMU evaluation at 0.38 g and 0.16 g
- The affect of a 24 h 36 m day might also be introduced.
- Testing of other HEDS hardware, such as a Transhab.

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Peak Physical Challenges

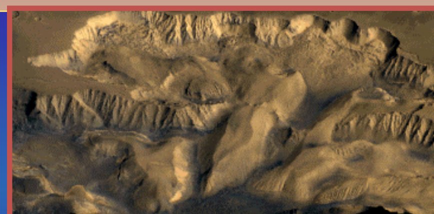
Mars Surface Phase
(post-landing through pre-launch)

Assumptions about Mars surface gravity

- Too ***LOW*** to be beneficial (for preserving bone integrity, etc.)
- Too ***HIGH*** to be ignored (for avoiding g-transition vestibular symptoms)

Challenges

- Physical
  - g-transition (first few days only?)
  - prolonged exposure to .38 g
  - high-intensity surface activity
  - EMU hypobaric environment
  - 70 kg EMU (partially self-supporting)
  - surface trauma risk
- Communications - no real-time MCC support (one-way communications: 3-22 min.)
  - crew highly autonomous
  - Earth monitoring for trend analysis only



EMU: extravehicular mobility unit
MCC: Mission Control Center

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Peak Physical Challenges

Strategy for Mars Surface Operations

Background → Anecdotal evidence suggests only ~50% of Russian *Mir* crewmembers are ambulatory *with assistance* immediately after landing, increasing to nearly 100% within hours

Assume → Only 3 out of 6 Mars crewmembers are ambulatory immediately after landing

Strategy → Start with passive tasks inside vehicle and progress to strenuous tasks on surface

- **First 1-3 days** activities limited to reconfiguration of lander/habitat and surface reconnaissance
- **Then**, conduct first Mars walk(s) in vicinity of lander (umbilical instead of backpack?)
- **Next,** use unpressurized rover for early, shorter excursions
- **After a week or more**, extended excursions are possible

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Life Sciences on the Martian Surface

Crew health care

- Medical care
- Nutrition
- Psychological support
  - meaningful work
    - surface science
      - planetary
      - biomedical
    - simulations of Mars launch, TEI, contingencies
    - progressive debriefs, sample processing, etc.
    - housekeeping
  - communications capability

Periodic (monthly?) health checks for:

- bone integrity
- cardiovascular/cardiopulmonary function
- musculoskeletal fitness
- hematological parameters

Health assessments will also serve as applied research:

- probably longest period away from Earth to date
- probably longest exposure to hypogravity (.38 g) environment to date

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Space Medicine Issues

Projected rates of illness or injury

Past Experience

0.06 person/year

Based on U.S. and Russian space flight data, U.S. astronaut longitudinal data, and submarine, Antarctic winter-over, and military aviation experience:

- Incidence of *significant* illness or injury is **0.06 per person per year**
  - as defined by U.S. standards
  - requiring emergency room visit or hospital admission

Mars DRM

0.90 person/mission

Expected incidence for a DRM of 6 crewmembers and 2.5 year mission is **0.90 person per mission,** approximately one person per mission

- Subset of injuries or illness requiring intensive care support is 0.02 per person per year
  - Expected incidence is 0.30 per mission, or about **once per three missions** (~80% of intensive care support lasts only 4-5 days)

Note: any such occurrences will also preoccupy onboard care-giver.

Data from R. Billica, January 1998, and D. Hamilton, June 1998

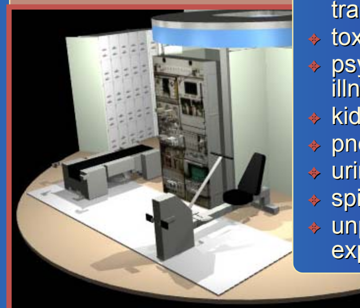
MARS

Space Medicine Issues

Reports of illness and injury during space flight

Incidence Common (>50%)

- skin rash, irritation
- foreign body
- eye irritation, corneal abrasion
- headache, backache, congestion
- gastrointestinal disturbance
- cut, scrape, bruise
- musculoskeletal strain, sprain
- fatigue, sleep disturbance
- space motion sickness
- post-landing orthostatic intolerance
- post-landing neurovestibular symptoms



Conceptualization of crew healthcare & exercise facilities

Incidence Uncertain

- infectious disease
- cardiac dysrhythmia, trauma, burn
- toxic exposure
- psychological stress, illness
- kidney stones
- pneumonitis
- urinary tract infection
- spinal disc disease
- unplanned radiation exposure

Data from R. Billica, Jan. 8, 1998

artwork from Constance Adams and Kris Kennedy for the JSC TransHab Team

MARS

Human Factors and Habitability

The following require engineering solutions:

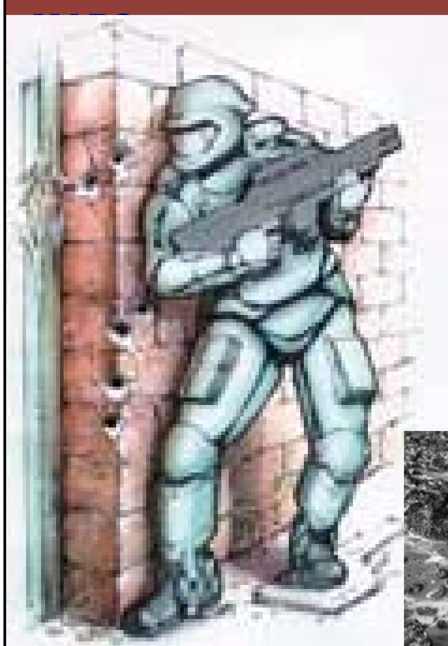
- air purifier
- water purifier
- particulate analyzer
- microbial analyzer
- waste manager/recycling
- food storage
- food processor
- clothing manager (e.g., washing machine)
- lighting levels
  - intensity (threshold level)
  - periodicity (circadian rhythmicity)

Optimal
Human
Health &
Performance

MARS

ICASE/LaRC WORKSHOP OBJECTIVE

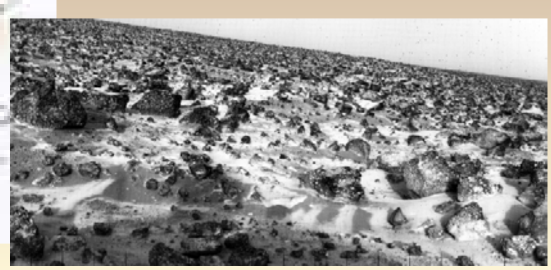
- Exploration of the solar system will be most effective if humans and robots are synergistically combined.
- The primary focus is to understand how, with the incorporation of revolutionary aerospace systems concepts over the next 10 - 40 years, humans and machines can be synergistically combined to physically and virtually reduce the time and distance barriers associated with exploring beyond low Earth orbit.



Exoskeletons

The military is betting millions that technology can turn soldiers into superhumans.

Engineering advances may soon lead to form-fitting, flexible exoskeletons like the one on the trooper in this artist's rendering. *DARPA*



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Exoskeletons

The DARPA regards exoskeleton technology promising enough to deserve a $50 million, 5-year commitment.

- Troops are less able to use armored vehicles to fight in urban battlefields.
- Planners want to fasten armor, heavy weapons, and electronics onto the foot soldiers themselves.
- Without mechanical support, people would collapse under the load.
- A U.S. marine is required to march 4 km/h carrying as much as 50 kgs of equipment.
- An exoskeleton-equipped marine may be able to move about three times that fast while carrying more than double the load.

Many similarities exist for EVA on a rock-strewn planet

- Rovers may not make good time in boulder field and may not be stable on slopes. They are of no use at all on some terrains.
- Massive EMU, equipment, and rock samples will be a burden for an astronaut, especially after months at O-g.

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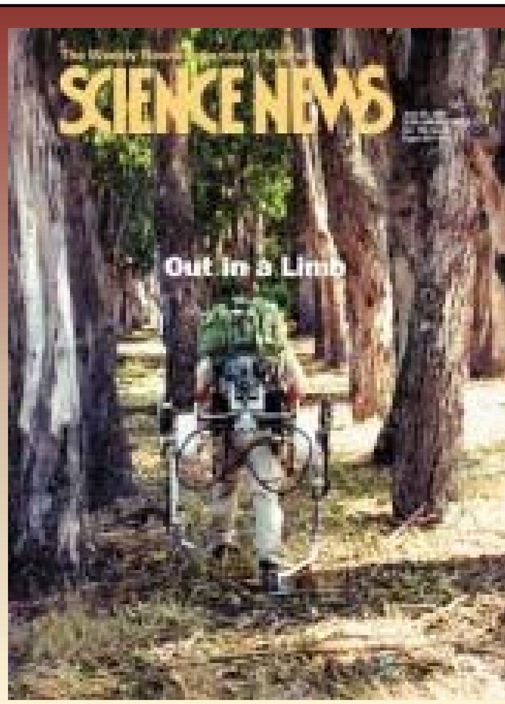

lower extremity enhancer

Kazerooni, *University of California, Berkeley*

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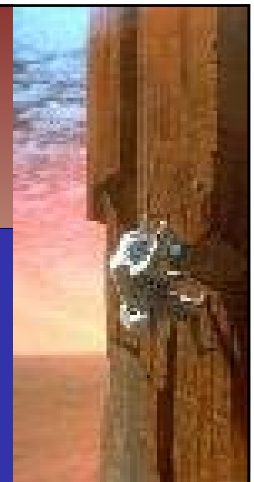

Potential Space Applications:

- Assist EVA crew after months at 0-g
- Navigate terrain inaccessible to rovers
- Support tools, samples, and instruments
- Incorporate elements of these technologies into manned free-flyers for asteroid exploration
- Provide capability for planetary surface EVA in very demanding situations, such as craters, cliffs, ice caps, etc.

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A pair of American explorers visit Phobos, Mars' innermost moon, in this painting by Pat Rawlings.

A prototype one-person flyer recently demonstrated enough thrust to be able to take off carrying a person. *Millennium Jet*

MARS

Control, Robotic Technologies

- Researchers at ORNL have developed a lifting machine that amplifies hand motions enough to manipulate large loads with precision.
  - The lifter enables its operator to raise a 2,200 kilogram bomb as if it weighed only 4 kg.
- To build a system in which a robot shadows every move a person makes is a complex undertaking.
  - After detecting the motion and gauging its speed and force, the robot must translate those readings into a parallel motion by some of its components.
  - All the while, other exoskeleton components have to adjust to maintain the system's balance.

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Challenges:

- framework materials
- actuators
- sensors
- control algorithms
- compact, portable, and ample source of power
- heat, noise, volume, and mass of each of these components

An exoskeleton could be intelligent enough to take care of the person wearing it. If the human is hurt, it could take him home.

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In the 1986 film Aliens, Sigourney Weaver as Lt. Ripley straps herself into an industrial loader — like a forklift with legs — to battle the hideous, mucus-covered alien queen.